RESEARCHES ON METEORITES.

I.

On October 4 I communicated to the Royal Society a preliminary note embodying some results I had obtained in observations on meteorites, undertaken with a view of obtaining additional information on some parts of the spectrum of the sun.

Some years ago I commenced a research on the spectra of carbon in connection with certain lines I had detected in my photographs (1874) of the solar spectrum. I have been going on with this work at intervals ever since; and certain conclusions to which it leads, emphasizing the vast difference between the chemical constitution of the sun and of some stars, recently suggested the desirability of obtaining observations of the spectra of meteorites and of the metallic elements at as low a temperature as possible.

I have latterly, therefore, been engaged on the last-named inquiries. The work already done, read in conjunction with the work on carbon, seems to afford evidence which amounts to demonstration on several important points.

The researches are still very far from complete, and the results must be given with great reserve, as the astronomical observations with which I have had to compare my laboratory work have been frequently made under conditions of very great difficulty.

A full report on the work, so far as it has gone, made to the Solar Physics Committee, which I have also communicated to the Royal Society, was read to-day, and I have received permission to publish part of it in this week's NATURE.

The general conclusions at which I have so far arrived may be stated as follows:—

I. All self-luminous bodies in the celestial spaces are composed of meteorites, or masses of meteoritic vapour produced by heat brought about by condensation of meteor-swarms due to gravity.

II. The spectra of all bodies depend upon the heat of the meteorites, produced by collisions, and the average space between the meteorites in the swarm, or in the case of consolidated swarms upon the time which has elapsed since complete vaporization.

III. The temperature of the vapours produced by collisions in nebulæ, stars without C and F but with other bright lines, and in comets away from perihelion, is about that of the bunsen burner.

IV. The temperature of the vapours produced by collisions in α Orionis and similar stars is about that of the Bessemer flame.

V. The line of increase of temperatures of the swarms of meteorites, and of subsequent cooling of the mass of vapour produced, and the accompanying phenomena, may be provisionally stated as follows:—

SEQUENCES OF SPACING AND TEMPERATURES (PROVISIONAL).

From Cold to Hot = Sparse to Dense Swarms.

	Spectrum of interspace.		Spectrum of vapour of meteorite.		Spectrum of meteorite.
	H.	C.	*Radiation.*	*Absorption.*	*Radiation.*
Nebulæ (without F)	Nil	Nil	Mg (500) ± 495	Nil?	Dimly continuous.
Comets 1866 and 1867	Nil	Nil	Mg (500)		
Nova Cygni after collision	Nil	Nil	Mg (500)		
Stars with bright lines (without F)	Nil	Nil	Fe, Mn	Broad band 475	
Nebulæ (with F)	H	Nil	Mg (500) ± 495	Nil?	Continuous.
Stars with bright lines (with F).	H	Nil	Fe, Mn	D and *b* and other lines and bands	
Comets under mean conditions of collision	Nil	C	Mg(*b*)	Nil.	Continuous.
Comets at perihelion	Nil	C	Meteorite lines.	(?)	
Stars, Class III.*a*	Nil	C		Meteorite flutings and lines	Vividly continuous.
Mixed swarms—					
R Geminorum	H	C	Meteorite lines.	Meteorite lines	
Nova Orionis at maximum.	H	C		Meteorite flutings and lines	
Condensation.					
Stars, Classes I. and II.			Continuous	High-temperature lines of substances present in meteorites	The radiation from individual meteorites now gives place to radiation from the interior vaporous and subsequently consolidated mass of the condensed swarm.
Subsequent Cooling.					
Stars: Class II. some stars, including sun			Continuous	K in excess	
Stars: Class III.*b*				Flutings of carbon	

VI. The brilliancy of these aggregations, at each (increasing) temperature, depends on the number of meteorites in the swarm—*i.e.* the difference depends upon the quantity, not the intensity, of the light.

VII. The existing distinction between stars, comets, and nebulæ rests on no physical basis.

VIII. The main factor in the various spectra produced is the ratio of the interspaces between the meteorites to their incandescent surface.

IX. When the interspace is very great, the tenuity of the gases given off by collisions will be so great that no luminous spectrum will be produced ("nebulæ" and "stars" without F bright). When the interspace is less, the tenuity of the gas will be reduced, and the vapours occupying the interspaces will give us bright lines or flutings ("nebulæ" and "stars" with F bright). When the interspace is relatively small, and the temperature of the individual meteorites therefore higher, the preponderance of the bright lines or flutings in the spectrum of the interspaces will diminish, and the incandescent vapour surrounding each meteorite will indicate its presence by absorbing the continuous-spectrum-giving light of the meteorites themselves.

X. The brighter lines in spiral nebulæ, and in those in which a rotation has been set up, are in all probability due to streams of meteorites with irregular motions out of the main streams, in which the collisions would be almost *nil*. It has already been suggested by Prof. G. Darwin[1]—using the gaseous hypothesis—that in such nebulæ "the great mass of the gas is non-luminous, the luminosity being an evidence of condensation along lines of low velocity according to a well-known hydrodynamical law. From this point of view the visible nebula may be regarded as a luminous diagram of its own stream-lines."

XI. New stars, whether seen in connection with nebulæ or not, are produced by the clash of meteor swarms, the bright lines seen being low-temperature lines of elements the spectra of which are most brilliant at a low stage of heat.

XII. Most of the variable stars which have been observed belong to those classes of bodies which I now suggest are uncondensed meteor-swarms, or stars in which a central more or less solid condensed mass exists. In some of those having regular periods the variation would seem to be partly due to swarms of meteorites moving around a bright or dark body, the maximum light occurring at periastron.

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[1] NATURE, vol. xxxi. p. 25.

XIII. The spectrum of hydrogen seen in the case of the nebulæ seems to be due to low electrical excitation, as happens with the spectrum of carbon in the case of comets. Sudden changes from one spectrum to the other are seen in the glow of meteorites in vacuum tubes when a current is passing, and the change from H to C can always be brought about by increased heating of the meteorite.

XIV. Meteorites are formed by the condensation of vapours thrown off by collisions. The small particles increase by fusion brought about again by collisions, and this increase may go on until the meteorites may be large enough to be smashed by collisions, when the heat of impact is not sufficient to produce volatilization of the whole mass.

XV. Beginning with meteorites of average composition, the extreme forms, iron and stony, would in time be produced as a result of collisions.

XVI. In recorded time there has been no such thing as a "world on fire" or the collision of masses of matter as large as the earth, to say nothing of masses of matter as large as the sun; but the known distribution of meteorites throughout space indicates that such collisions may form an integral part of the economy of Nature. The number of bodies, however, subject to such collision is small, and must, it would appear, form but a small percentage of the celestial bodies, seeing that they must be consolidated.

XVII. *Special solar applications.*

a. The solar spectrum can be very fairly reproduced (in some parts of the spectrum almost line for line) by taking a composite photograph of the arc spectrum of several stony meteorites, chosen at random, between iron meteoric poles.

β. The carbon which originally formed part of the swarm the condensation of which produced the sun has been dissociated by the high temperature brought about by that condensation.

γ. The indications of carbon which I discovered in 1874 (Proc. R.S., vol. xxvii. p. 308) will go on increasing in intensity slowly until a stage is reached when, owing to the reduction of temperature of the most effective absorbing layer, the chief absorption will be that of carbon—a stage in which we now find the stars of Class III.*b* of Vogel's classification.

δ. At the present time it seems probable that among the chief changes going on in the solar spectrum are the widening of K and the thinning of the hydrogen lines.

EXPERIMENTS UPON WHICH THE FOREGOING CONCLUSIONS DEPEND.

A. Experiments upon carbon.

The main conclusions which may be stated here are that there are two systems of flutings which depend upon temperature only.

At low temperatures all compounds of carbon give a set of simple flutings, the brightest of which are at wave-lengths 4510, 4830, 5185, and 5610. At higher temperatures there is a series of compound flutings, the brightest edges of which are at wave-lengths 4380, 4738, 5165, and 5640. In the case of compounds of carbon with hydrogen there is an additional fluting at wave-length 4310, and this is the only criterion for the presence of hydrocarbon among the flutings shown on the map. (See Map 3.)

B. Experiments upon the luminous phenomena of the various metals volatilized in the bunsen burner and the oxy-coal-gas blow-pipe flame as compared with the phenomena seen at higher temperatures.

The main conclusions are that certain lines, bands, and flutings are seen in the bunsen burner, that a larger number is seen in the flame, and that the total number seen in the burner and flame is small.

The order of visibility in the bunsen is, roughly—

Lines ...	Mg Na Li Tl Sr Ba Ca K Mn Bi
Bands	Ca Sr Ba
Flutings	Mg Mn

All the observations both of bunsen and oxyhydrogen flame may be condensed as follows:—

In metals of the alkalies	Na K Li
,, ,, alkaline earths ...	Ca Sr Ba
In magnesian metals	Mg Zn Cd
In iron metals	Fe Ni Co Mn Cr
In metals which yield acids	Bi Ti W
In copper metals	Cu Tl
In noble metals	Ag Hg
In earthy metals	Ce

The following table shows the positions of the principal lines, bands, and flutings seen in the spectrum of each of the metals examined, arranged roughly in the order of their intensities.

It should here be stated that as some of the researches have had to deal with feeble illumination small dispersion has been of necessity employed, and to make the observations along the several lines comparable a one-prism spectroscope has been so far used throughout. Hence the wave-lengths given are in all cases only approximate. With this proviso the lines observed have been as follows:—

Lines	*In bunsen—*	
	Mg	5183, 5172, 5167, 4586, 5201.
	Na	5889, 5895.
	Li	6705.
	Tl	5349.
	Sr	4607.
	Ba	5534.
	Ca	4226.
	Mn	5395.
	K	6950.
	Bi	4722.
	Seen on passing from the temperature of the bunsen to that of the oxy-coal-gas flame—	
	Fe	5268, 5327, 5371, 4383, 5790, 6024.
	Cu	5105, 5781, 5700.
	Cr	5202, 5203, 5207, 5410.
	Zn	4810, 4911.
	Cd	5085.
	Ni	5476.
	Ti	5128, 5338.
	W	5490, 5511.
	Ag	5208, 5464.
	Hg	5460.
	Ce	5273, 5160.
Bands	*In bunsen—*	
	Ca	5535, 6250, 6500, 6000.
	Sr	6050.
	Ba	5150, 5250, 5330, 4860.
	Seen on passing from the temperature of the bunsen to that of the oxy-coal-gas flame—	
	Co	4710, 4920, 5170, 5460.

Flutings

In bunsen—

Mg	5000
Mn	5580, 5860, 6145, 5340

Seen on passing from the temperature of the bunsen to that of the oxy-coal-gas flame—

Ba	6010, 6350, 6480
Cr	5360, 5570, 5800, 6040
Fe	6150
Cu	6050, 6130
Zn	5460, 5680, 4985, 5140, 5340

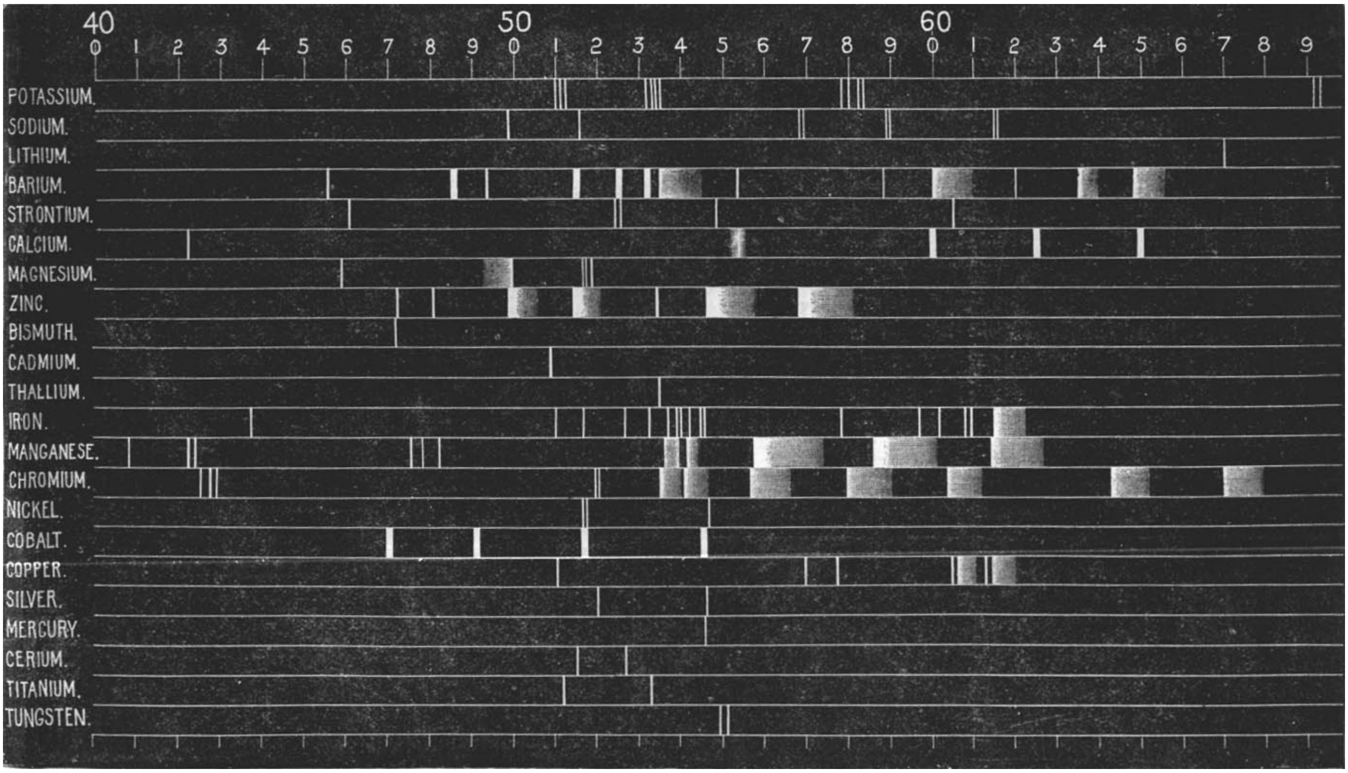
All the flutings, with the exception of magnesium, have their maxima towards the blue, and shade off towards the red end of the spectrum. (See Map 1.)

C. Experiments upon Mg at low temperatures.

I have again gone over the experiments already communicated to the Royal Society (Proceedings, vol. xxx. p. 27), and in addition have observed the spectrum of the metal burning in the centre of a large bunsen burner, in which case we get the line at 5201, and the fluting in the position of *b* without the fluting at 500. In the Bunsen as ordinarily employed the fluting at 500 far eclipses the other parts of the spectrum in brilliancy, and at this temperature, as already observed by Messrs. Liveing and Dewar (Proc. R. S. vol. xxxii. p. 202), the ultra-violet line visible is that at 373. Lecoq de Boisbaudran has observed the lines in the chloride at 4705 and 4483 ("Spectres Lumineux," p. 85).

D. Experiments upon the glow of Na and Mg in vacuum tubes.

A small piece of sodium, free from hydrocarbon, was placed in the lower limb of an end-on spectrum tube, and arrangements made for observing the spectrum of the gas evolved when the sodium was heated. Having first obtained as perfect a vacuum as possible, the sodium was gently heated, and the spectrum of the gas then gave nothing but the C and F lines of hydrogen. The pump being stopped and the sodium heated, a point was reached when C and F became very dim and were replaced by the structural spectrum of hydrogen.



MAP 1.—Spectra of metals at the temperature of the oxy-coal-gas blowpipe.

In another experiment the sodium was replaced by a piece of magnesium along the end-on tube. The same process being gone through, similar phenomena were observed, but in the latter case there was a line at 500, in addition to the lines seen in the case of sodium.

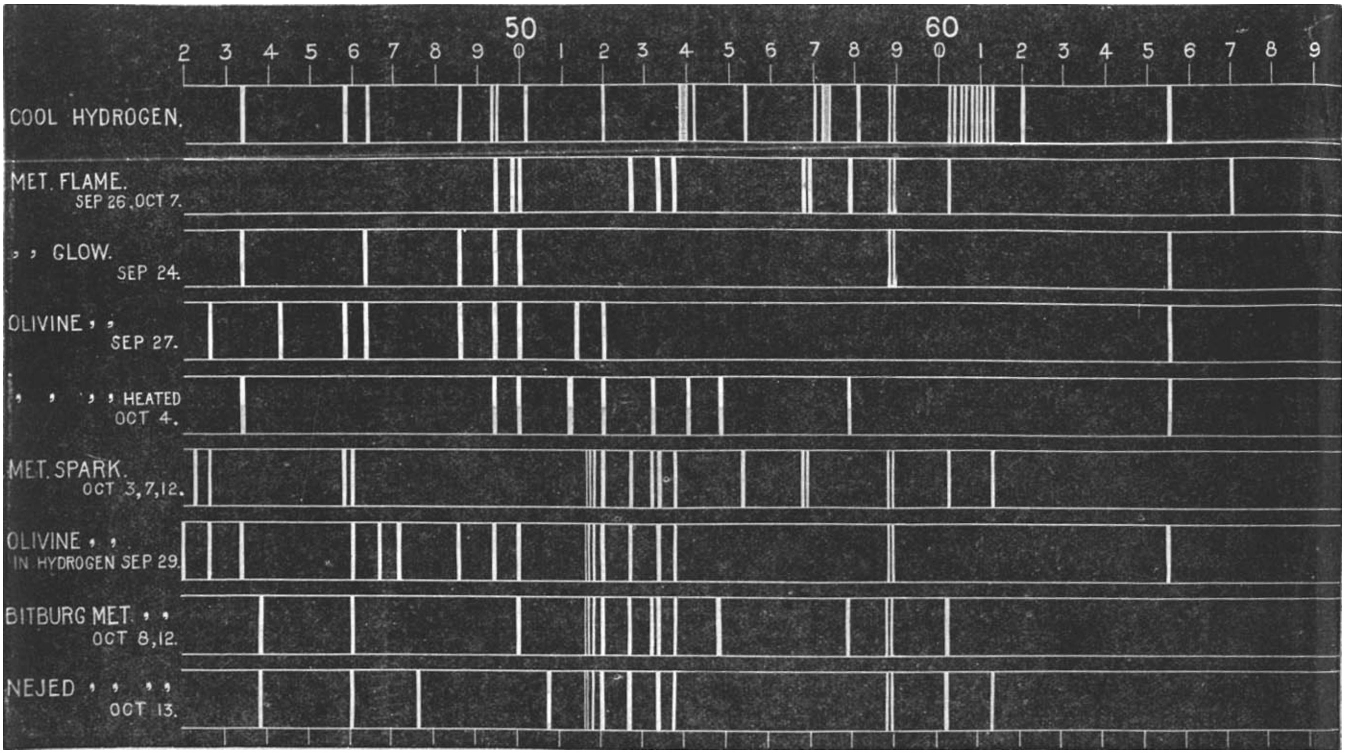
The important point, then, is the existence of a line at 500 in the spectrum when magnesium is heated, and the absence of such a line in the gas evolved from sodium under the conditions stated.

E. Experiments upon the conditions under which the C and F lines of hydrogen disappear from the spectrum.

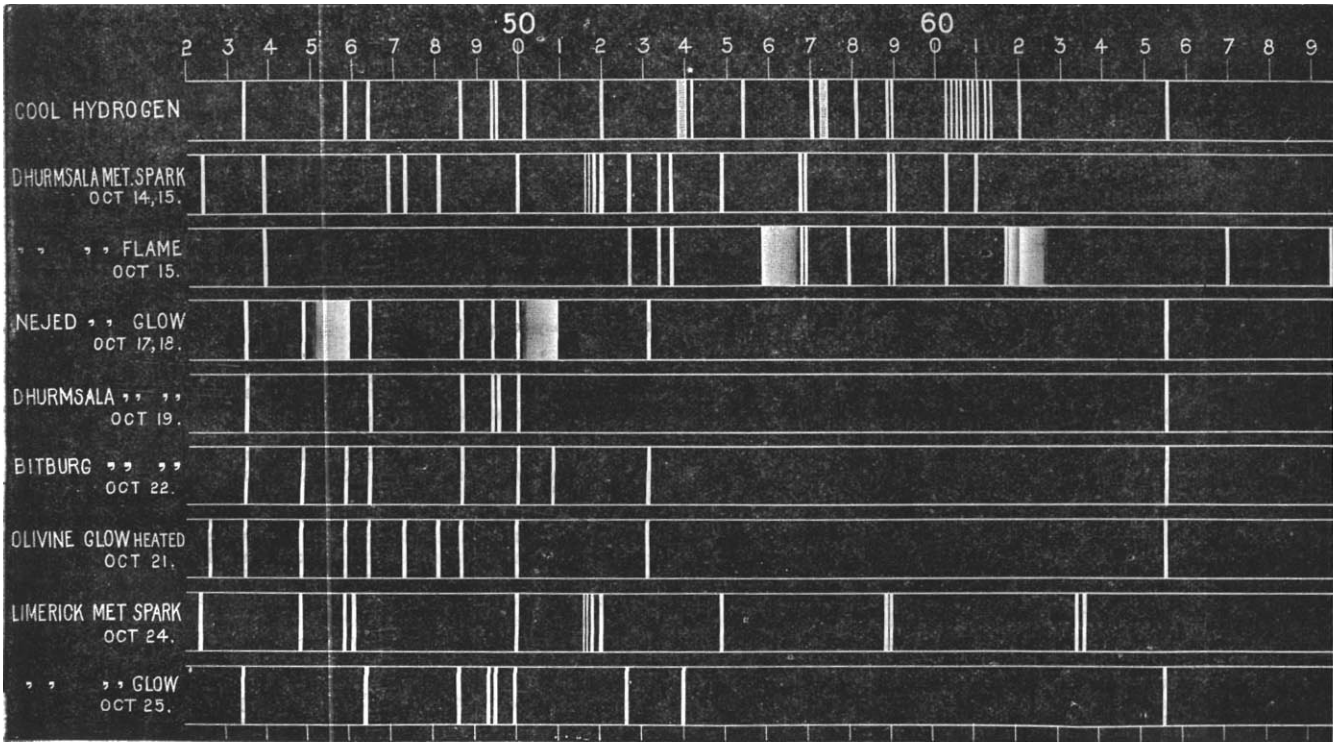
The association of the bright lines of hydrogen with nebulæ and many of the stars with bright lines and the so-called new stars points out at once that it is important to consider the various changes which hydrogen can undergo under various conditions of temperature and pressure. I pointed out many years ago that, when under certain conditions the spectrum of hydrogen is examined at the lowest possible temperature, the F line retains its brilliancy long after C disappears; and the fact that, after all the lines of hydrogen may be made to disappear from the spectral tube, the spectrum which remains visible, and is sometimes very brightly visible, is also due to hydrogen, has always been a matter of thorough belief in my mind, although so many observers, down even to M. Cornu not so very long ago, have been inclined to attribute it to the existence of "impurities."

I began to map the so-called structural spectrum at the College of Chemistry in 1869, but other matters supervened which prevented the accomplishment of this work. This, however, is a matter of small importance, because quite recently Dr. Hasselberg has communicated to the St. Petersburg Academy an admirable memoir on the subject, accompanied by a map (Mémoires de l'Académie Impériale, series vii. vol. xxx. No. 7, Hasselberg). The brightest portions of the structure spectrum are shown in Map 2.

The most convenient way of obtaining a supply of hydrogen for investigations of this kind is to use a little sodium which has never been in contact with hydrocarbon, or a piece of magnesium wire; to place them in the low end of a glass tube, one part of



Map 2.—Spectra of olivine and meteorites under various conditions.



Map 2A.—Spectra of olivine and meteorites under various conditions.

which can be used as an end-on tube, and then, after getting a vacuum so perfect that the spark will not pass, to slightly heat the metal. After a time the spectrum of hydrogen, sometimes accompanied by the low-temperature flutings of carbon, begins to be visible alike from the sodium and the magnesium.

If the vacuum has been very perfect to start with, the bright lines C and F will at first be visible without any trace of structure, and the hydrogen will be of a magnificent red colour. If now the action of the pump be stopped and the sodium be still more heated, a point will be reached at which the conductibility of the gas is at its maximum, and then, the jar not being in circuit, the structure-spectrum of the gas will be seen absolutely alone, without any trace of either C or F. The gradual disappearance of the F line is very striking, and when the bright line is out of the field the lines due to the structure seem to be enhanced in brilliancy.

The brightest part of the spectrum is then that near D; in the blue-green we have a line at 464 more refrangible than F, and then a doube line at 4930 and 4935; other less refrangible lines are seen. These are phenomena seen associated with sodium, but if we use the hydrogen produced from a piece of magnesium wire or from a crystal of olivine, under the same circumstances we find that so far as the lines of hydrogen go the phenomenon remains the same, but that there is then visible in the spectrum a line at 500, which has been recorded in the spectrum of magnesium under other conditions, not only by myself but by Dr. Copeland.[1]

F. Experiments upon the spectra of meteorites at low temperatures.

All the later observations recorded have been made on undoubted meteorites, fragments of which have been in the kindest manner placed at my disposal.

I. In the oxyhydrogen flame.

The observations gave in all only about ten or a dozen lines belonging to the metals magnesium, iron, sodium, lithium, and potassium, and two flutings, one of manganese, and one of iron.

II. With a quantity coil without jar.

The observations gave in all about twenty lines belonging to the metals magnesium, sodium, iron, strontium, barium, calcium, chromium, zinc, bismuth, and nickel, and four lines of unknown origin.

III. When heated in a vacuum tube when a current is passing along it.

A small piece of iron meteorite was inclosed in the middle of a horizontal tube, so that the spark might be made to pass through the tube and over the meteorite. After complete exhaustion has been obtained, the first spectrum observed when the tube, end on, is placed in front of the spectroscope, is a spectrum of hydrogen. The carbon flutings are only visible occasionally. If the meteorite then be very gently warmed by placing a Bunsen burner at some distance below the tube, the glow over the meteorite is seen to change its colour, and the line at 500 is constantly, and another line at 495, apparently exactly in the position of the second line of the spectrum of the nebulæ, is occasionally, seen. This line is more refrangible than the structure line of hydrogen in this region, which occupies the same position as the barium line. This, however, if the heating is continued, especially in the case of stony meteorites, is soon succeeded by a much more brilliant green glow, in which magnesium *b* and many other lines appear, now accompanied by the carbon flutings. The observations made under all the above conditions are shown in Maps 2 and 2A.

In these observations if a line in the meteorite spectrum were coincident with a metallic line, with the dispersion employed, in the absence of the brightest line of that metal, the line was regarded as originating from some other substance. Thus a line was sometimes seen at 5480, apparently coincident, with the dispersion employed, with the green lines of Sr and Ni; sometimes the brightest line of Sr at 4607 was absent, and it was then fair to assume that the presence of 5480 was due to Ni, but in the presence of 4607 it might be due to Sr.

Comparisons of the Foregoing Observations among themselves and with those made on Various Orders of Celestial Bodies.

The discussions have taken, in the first instance, the form of comparisons of the different phenomena observed, and for this purpose all recorded observations of flutings and bright lines and dark lines in stars, comets, nebulæ, &c., have been carefully mapped in addition, all records having, when necessary, been brought to a common scale. Having these maps, I could then compare the totality of celestial observations with the laboratory work to which reference has already been made.

The following are among the comparisons already dealt with:—

I. The spectra of meteorites observed under the various conditions, chiefly considering magnesium, iron, and manganese, with the bright lines observed at low temperatures.

The main conclusions are:—

(1) That only the lowest temperature lines of Mg, Na, Fe, Cr, Mn, Sr, Ca, Ba, K, Zn, Bi, and Ni are seen in the meteorites under the various conditions. They are not all seen in one meteorite or under one particular condition; the details of individual observations are fully recorded in Maps 2 and 2A.

(2) That in the case of Mg the line most frequently seen is the remnant of the fluting at 500, while in a photograph the main ultra-violet line recorded is the one at 373, previously recorded under these conditions by Messrs. Liveing and Dewar. In the quantity spark other lines are seen, notably b_1, b_2, b_4, and 5201. The line at 500 was considerably brightened when the number of cells was reduced, thus showing it to be due to some molecule which can exist best at a low temperature.

(3) That in the case of Mn the only line visible at the temperature of the bunsen burner, 5395, is the only line seen in the meteorites.

(4) That the lines of iron seen in the meteorites are those which are brightest when wire gauze is burned in the flame. The chief of these are 5268, 4383, 5790, and 6024; it is possible, however, that the two latter are due to some substance, not iron, common to the gauze and the meteorites.

II. The spectra of meteorites generally, with the bright lines and flutings seen in luminous meteors, comets, and some "stars."

a. Luminous meteors.

With regard to the records of luminous meteors, it may be remarked that the observations, so far as they have gone, have given decided indications of magnesium, sodium, lithium, potassium, and of the carbon flutings seen in comets. The following quotations from Konkoly and Prof. Herschel are among the authorities which may be cited for the above statement.

"On August 12, 13, and 14, I observed a number of meteors with the spectroscope; amongst others, on the 12th, a yellow fireball with a fine train, which came directly from the Perseid radiant. In the head of this meteor the lines of lithium were clearly seen by the side of the sodium line. On August 13, at 10h. 46m. 10s., I observed in the north-east a magnificent fireball of emerald-green colour, as bright as Jupiter, with a very slow motion. The nucleus at the first moment only showed a very bright continuous spectrum with the sodium line; but a second after I perceived the magnesium line, and I think I am not mistaken in saying those of copper also. Besides that, the spectrum showed two very faint red lines."[1]

"A few of the green 'Leonid' streaks were noticed in November (1866) to be, to all appearances, monochromatic, or quite undispersed by vision through the refracting prisms; from which we may at least very probably infer (by later discoveries with the meteor-spectroscope) that the prominent green line of magnesium forms the principal constituent element of their greenish light."[2]

Again, later on in the same letter, Prof. Herschel mentions Konkoly's observation of the bright *b* line of magnesium in addition to the yellow sodium line in a meteor on July 26, 1873.

I again quote from Prof. Herschel:—

"On the morning of October 13 in the same year, Herr von Konkoly again observed with Browning's meteor-spectroscope the long-enduring streak of a large fireball, which was visible to the north-east of O'Gyalla. It exhibited the yellow sodium line and the green line of magnesium very finely, besides other spectral lines in the red and green. Examining these latter lines closely with a star-spectroscope attached to an equatorial telescope, Herr von Konkoly succeeded in identifying them by direct comparison with the lines in an electric Geissler-tube of marsh-gas. They were visible in the star-spectroscope for eleven minutes, after which the sodium and magnesium lines still continued to be very brightly observable through the meteor-spectroscope."[1]

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[1] "To this table must be added 500·6 mmm. as the wave-length of the first line in the great band of magnesium as determined by M. Lecoq de Boisbaudran from the spark-spectrum of the chloride of that metal, which evidently agrees with the flame-spectrum, in this region at least. It is worthy of note that this line almost absolutely coincides with the brightest line in the spectra of planetary nebulæ" (Dr. Copeland, *Copernicus*, vol. ii. p. 109).

[1] Konkoly, *Observatory*, vol. iii. p. 157.

[2] Herschel, letter to NATURE, vol. xxiv. p. 507.

The green line "*b*" of magnesium occurring as a bright line in luminous meteors indicates that their temperature when passing through our atmosphere is higher than that of the bunsen, and we may add of comets as generally observed, although some exhibit the *b* lines of magnesium and those of iron when at perihelion, as shown later on.

The two lines which Konkoly supposes are probably due to copper will, I expect, be found to be iron lines when other observations are made of the spectra of meteors.

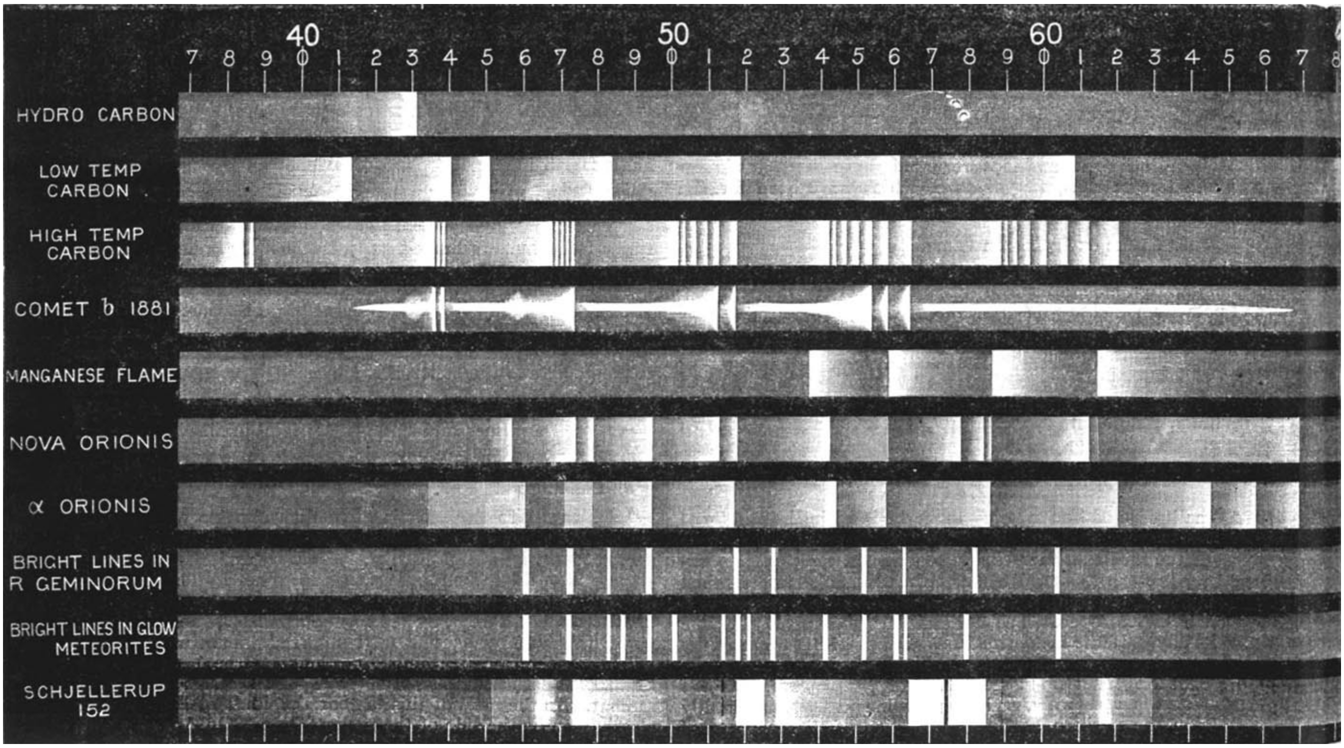
The main conclusions from this comparison are then: (1) that the temperature of luminous meteors is higher than that of the bunsen flame; (2) that the meteorites which produce the phenomena we are now discussing are hotter than those in the experimental glow taken generally; and (3) that in both cases flutings of carbon may be seen.

β. Comets.

When the meteorites are *strongly* heated in a glow-tube, the whole tube when the electric current is passing gives us the spectrum of carbon.

When a meteor-swarm approaches the sun, the whole region of space occupied by the meteorites, estimated by Prof. Newton in the case of Biela's comet to have been thirty miles apart, gives us the same spectrum, and further it is given by at all events part of the tail, which in the comet of 1680 was calculated to be 60,000,000 miles in length. The illumination therefore must be electrical, and possibly connected with the electric repulsion of the vapours away from the sun; hence it is not dependent wholly upon collisions.

Passing now from the flutings seen in cometary spectra, it is found that most of the lines which have been observed at perihelion are coincident with lines seen in experiments with meteorites, while the low temperature lines of Mg are absent. In the great comet of 1882, to which particular attention has been given on account of the complete record of its spectrum by Copeland,[2] the lines recorded were the D lines of sodium, the low-temperature iron lines at 5268, 5327, 5371, 5790, and 6024, the lines seen in the manganese spectrum at the temperature of the bunsen burner at 5395 and 5425, and a line near *b* which might be due to magnesium, or to a remnant of the carbon fluting. In addition to these there was a line at 5475, probably due to nickel, the absence of the blue strontium line indicating that it is not likely to be the green line of strontium. There were also four other lines less refrangible than D, the origin of which has not yet been determined. As the comet got further from perihelion the lines gradually died out, those which remained longest being the iron line at 5268 and the line near *b*. The absence of D before the disappearance of all the lines is probably to be accounted for partly by the greater brightness of the continuous spectrum in that region.



MAP 3.—Comparison of flutings seen in the spectra of "stars" and comets with flutings of carbon, manganese, and zinc; and, in the case of R Geminorum, lines with remnants of flutings and lines seen in a meteorite glow. (The Zn fluting is at λ 544 in α Orionis.)

In the comets of 1866–67, when seen away from the sun, the only line seen was the one at 500.[1]

It is fair to myself to say that I was not aware of these observations when I began to write this paper. The fact of the line at 500 remaining alone in Nova Cygni made it clear that if my views were correct, the same thing should happen with comets. It now turns out that the crucial observation which I intended to make was made twenty years ago.

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[1] Herschel, letter to NATURE, vol. xxiv. p. 507.

[2] *Copernicus*, vol. ii. p. 234.

[1] "In January 1866 I communicated to the Royal Society the result of an examination of a small comet visible in the beginning of that year (Proc. R.S. vol. xv. p. 5). I examined the spectrum of another small and faint comet in May 1867. The spectra of these objects, as far as their feeble light permitted them to be observed, appeared to be very similar. In the case of each of these comets the spectrum of the minute nucleus appeared to consist of a bright line between *b* and F, about the position of the double line of the spectrum of nitrogen, while the nebulosity surrounding the nucleus and forming the coma gave a spectrum which was apparently continuous" (Huggins, Proc. R.S. vol. xvi. p. 387).

In Comets *b*, 1881, and *c*, 1882, the only lines recorded were magnesium *b*; but, as before, the apparent absence of other lines might be due to continuous spectrum.

Of the five bands shown in Huggins's photograph of the spectrum of Comet Wells, taken with a wide slit, no less than three agree fairly in position with three lines seen in the spectra of meteorites. The wave-lengths of these are 4253, 4412, and 4769, and it is interesting to note that, so far, the origin of these lines is undetermined. The two remaining bands are at wave-lengths 4507 and 4634.

It is seen, then, that the spectra of comets—when their internal motions are relatively either slow or fast, and when therefore the number of collisions, and with them the heat of the stones in collision, will vary extremely—resemble the spectra of meteorites seen in glow tubes.

(γ) "Stars" with flutings which have been observed in the laboratory and in luminous meteors and comets.

The most prominent bright flutings of carbon are not only observed in luminous meteors and comets, but in stars of Class III.*a*, and in some "Novas," notably Nova Orionis. So far, then, these bodies may in a certain measure be classed with luminous meteors and comets. But there is an important difference in the phenomena, for we have absorption as well as radiation. The discussion shows that the dark (or absorbing) flutings in these bodies are partly due to the absorption of light by the most prominent flutings of Mn and Zn, seen at low temperatures. This inquiry is being continued.

We have, then, in these bodies a spectrum integrating the *radiation* of carbon and the *absorption* of Mn and Zn vapour.

The law of parsimony compels us to ascribe the bright fluting of carbon in these stars to the same cause as that at work in comets, where we know it is produced by the vapours between the individual meteorites or repelled from them.

Hence we are led to conclude that the absorption phenomena are produced by the incandescent vapour surrounding the individual meteorites which have been rendered intensely hot by collisions.

These stars, therefore, are not masses of vapour like our sun, but clouds of incandescent stones.

We have here probably the first stage of meteoritic condensation.

J. NORMAN LOCKYER.

(*To be continued.*)

FAIRY-RINGS.

THE rains have come, and we have heard from all sides of the prolific crops of mushrooms and toadstools —paddock-stools, as they are termed in some northern districts—which have been springing up in the meadows and woods of England, Wales, and Scotland. Not only is surprise evinced at the marvellously rapid up-growth of these fungi, for the popular mind may well be amazed at that until a knowledge of the biology of these plants is more universal, but country people and dwellers in towns alike exclaim at certain other phenomena associated with their growth in the fields, and at none, perhaps, so much as what have been known from of old as "Fairy-rings" in England, *Hexenringe* and *Cercles de sorcières* on the Continent. Now fairy-rings, like very many other poetical objects, have of late years undergone the process of being explained away to an extent which, although it in no way removes the beauty from them, demands from us an admiration of a more stimulating and healthful character than the old awe which they inspired was capable of producing.

Disbelief prevails regarding Prospero and the beings that

> "By moonshine do the green sour ringlets make,
> Whereof the ewe not bites;"

and

> "whose pastime
> Is to make midnight mushrooms."

Fairy-rings are more or less regular and complete rings of grass, sharply distinguished from the ordinary grass surrounding them by means of their darker hue, more luxuriant growth, and other characters; in spring or autumn they are to be found with vigorous growths of mushrooms or toadstools springing from their outer margins, and the centre of the ring is often marked by a very poor crop of withered-looking herbage.

Before proceeding to give an account of the modern explanation of these remarkable objects, a few statements may be made as to their sizes, structure, and occurrence.

They are not always complete or regular rings, but may be parts of circles or ovals, or mere wavy strips. Nor are they always provided with the outer belt of fungi, though the rule is that a good season sees them so accompanied; if not, they do not remain long. In the typical cases, where the ring is annually provided with its fringe of fungi, it may go on increasing in size for years: records exist of rings which have been known to go on flourishing for forty or sixty years, and large rings on a hill-side could be seen from a considerable distance.

As to their sizes, they are known to commence as very small patches, but specimens have been measured as much as 60 feet and more in diameter. Indeed one observer refers to a fairy-ring which was nearly 100 feet across. While regarding these cases as rare extremes, it is well known that rings 12–20 feet in diameter have often been recorded, and, as we shall see, these must be several or many years old.

Although fairy-rings are usually noticed in meadows and on pasture lands, they are found on hills as well as in valleys, on dry soil as well as on wet, in woods and on heaths, and even in rocky places and situations near the sea. Perhaps the only generalization possible in this connexion is that they do not occur on highly-cultivated rich land.

On regarding carefully a typical fairy-ring, it may be found to present the following characters:—The central area, encompassed by the dark-green ring, consists of poor or even withered herbage—it may be of inferior grasses alone, or of these mixed with other plants. Then comes the band of luxuriant grass forming the ring proper: the grass composing this may be of more than one kind—*e.g. Lolium perenne* (the perennial rye-grass), *Dactylis glomerata* (the cock's-foot grass), and *Bromus mollis* (the soft brome) are common.

These grasses are rank, tall, and of a distinctly darker, bluer green hue than the rest; it is their coarseness, height, and especially the deeper colour, which render them so prominent. Fringing this ring, at the proper season, are found the spore-bearing heads of the Agarics *i.e.* the mushrooms or toadstools as the case may be; and if the observer digs carefully below the soil, he will find that these Agarics spring from a felted mass of root-like threads, the mycelium of the fungus. Then, outside all, comes the general herbage of the pasture, or whatever it may be: this is often scanty, indicating poor soil, and in any case is less luxuriant and lighter in colour than the rank herbage of the ring itself.

As with the herbage composing the rings, so the Agarics fringing them may be of different kinds. In the autumn the fairy-rings of this country and on the Continent commonly contain *Marasmius oreades*, Fr., a small pale mushroom with cream-coloured gills, and much esteemed as an esculent. It has a somewhat strong aromatic odour, and its mycelium is attached to the roots of the grasses among which it grows. It must not be confounded with certain acrid species allied to it.

The common mushroom (*Agaricus campestris*, L.) is also frequently found in large circles, fringing more or less complete fairy-rings. Among other forms may be mentioned the gray *Agaricus terreus*, Schoeff, not uncommon in beech- and fir-woods; the "parasol mushroom" (*Agaricus procerus*, Scop.), also not uncommon in fir-woods and pastures, and spoken of as one of the best of the esculent forms; also *Agaricus personatus*, Fr., with a lilac or purple stem. This is a late form,